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SCIENCE EXPLORE-An International Journal on Science and Knowledge in General
ISSN: 3139-2997 (Online)
Volume I, Issue 2
July - December 2026

NUTRACEUTICALS: BRIDGING NUTRITION AND PHARMACOLOGY

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ABSTRACT

Nutraceuticals have emerged as a rapidly expanding field at the intersection of nutrition, medicine, and pharmacology, offering promising approaches for disease prevention, health promotion, and therapeutic support. Derived from food sources and bioactive compounds, nutraceuticals include dietary supplements, functional foods, herbal products, probiotics, and fortified foods that provide physiological benefits beyond basic nutrition. Growing interest in lifestyle-related disorders such as cardiovascular diseases, diabetes mellitus, obesity, cancer, and neurodegenerative conditions have intensified research into the preventive and therapeutic potential of nutraceuticals. This review explores the concept, classification, and mechanisms of action of nutraceuticals, emphasizing their role in modulating metabolic pathways, oxidative stress, inflammation, and immune responses. The article also highlights major bioactive compounds, including polyphenols, flavonoids, omega-3 fatty acids, probiotics, vitamins, and minerals, along with their pharmacological relevance and clinical applications.

KEYWORDS: Lifestyle disorders, Dietary supplements, Bioactive compounds, Functional foods, Probiotics

INTRODUCTION

The relationship between nutrition and health has been recognized since ancient times, where food was considered an important component of disease prevention and treatment. In modern healthcare, this concept has evolved into the field of nutraceuticals, which integrates nutrition and pharmacology to provide therapeutic benefits beyond basic nutritional requirements (DeFelice, 1995). The term “nutraceutical” was introduced by Stephen DeFelice in 1989 to describe food-derived products that offer medical or health benefits, including disease prevention and treatment (Kalra, 2003). Nutraceuticals have gained widespread attention because of the increasing prevalence of chronic diseases and the growing demand for safer, natural, and preventive healthcare approaches (Santini & Novellino, 2018).

Lifestyle-related disorders such as cardiovascular diseases, diabetes mellitus, obesity, cancer, and neurodegenerative disorders have become major global health concerns. These diseases are strongly associated with unhealthy dietary habits, sedentary lifestyles, oxidative stress, and chronic inflammation (Nasri et al., 2014). Conventional pharmaceutical therapies are often associated with adverse effects, high treatment costs, and limitations in long-term disease prevention. As a result, researchers and healthcare professionals are increasingly exploring nutraceuticals as complementary therapeutic agents with fewer side effects and broader preventive potential (Pandey et al., 2010).

Nutraceuticals include a wide variety of products such as dietary supplements, functional foods, herbal products, probiotics, prebiotics, and fortified foods (Hardy, 2000).

Functional foods are foods that provide physiological benefits beyond their basic nutritional value, while dietary supplements contain concentrated bioactive compounds such as vitamins, minerals, amino acids, and herbal extracts (Shahidi, 2009). These products contain biologically active compounds capable of modulating metabolic and cellular processes involved in disease progression.

Oxidative stress and inflammation are major contributing factors in the development of chronic diseases. Nutraceutical compounds such as polyphenols, flavonoids, carotenoids, vitamins, and omega-3 fatty acids exhibit strong antioxidant and anti-inflammatory properties that help reduce cellular damage caused by reactive oxygen species (Sirtori et al., 2009). Polyphenols present in fruits, vegetables, tea, cocoa, and wine have demonstrated cardioprotective, anticancer, and neuroprotective effects through modulation of inflammatory pathways and cellular signaling mechanisms (Shahidi, 2009).

Curcumin, a bioactive compound derived from turmeric, has gained considerable scientific interest due to its antioxidant, antimicrobial, anti-inflammatory, and anticancer properties (Nasri et al., 2014). Similarly, resveratrol found in grapes and berries has shown potential in cardiovascular protection and healthy aging because of its ability to regulate oxidative stress and inflammatory responses (Santini et al., 2017). Omega-3 fatty acids such as eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) are also important nutraceuticals known for their beneficial effects on cardiovascular and neurological health (Sirtori et al., 2009).

Probiotics and prebiotics represent another important category of nutraceuticals due to their role in maintaining gut microbiota balance and supporting immune function. Probiotics are live microorganisms that confer health benefits when administered in adequate amounts, whereas prebiotics are nondigestible substances that stimulate the growth of beneficial intestinal bacteria (Hardy, 2000). Studies suggest that probiotics may help manage gastrointestinal disorders, allergies, obesity, and metabolic diseases by improving intestinal health and modulating immune responses (Santini et al., 2017).

The role of nutraceuticals in preventive medicine has become increasingly significant in recent years. Preventive healthcare focuses on reducing disease risk before clinical symptoms appear, thereby lowering healthcare costs and improving quality of life (Santini et al., 2017). Nutraceuticals can help regulate blood glucose levels, blood pressure, lipid metabolism, immune function, and inflammatory pathways, thereby reducing the risk of chronic diseases (Nasri et al., 2014). Plant sterols, soluble fibers, antioxidants, and omega-3 fatty acids have demonstrated significant benefits in cardiovascular disease prevention by improving lipid profiles and endothelial function (Sirtori et al., 2009).

In addition to cardiovascular diseases, nutraceuticals have shown promising potential in diabetes management. Bioactive compounds such as dietary fibers, chromium, alpha-lipoic acid, and curcumin may improve insulin sensitivity and regulate glucose metabolism (Pandey et al., 2010). Functional foods with low glycemic indices also contribute to better glycemic control and weight management.

Cancer prevention is another major area of nutraceutical research. Several phytochemicals including lycopene, sulforaphane, catechins, and genistein possess anticancer activities through mechanisms such as apoptosis induction, inhibition of tumor growth, and suppression of angiogenesis (Shahidi, 2009). Although nutraceuticals cannot replace conventional cancer therapies, they may complement standard treatment strategies and improve patient outcomes.

The development of nutrigenomics and personalized nutrition has further expanded the scope of nutraceutical research. Nutrigenomics studies the interactions between dietary components and genes, aiming to develop individualized nutritional interventions based on genetic profiles (Santini & Novellino, 2018). This emerging field may contribute significantly to precision medicine and personalized healthcare in the future.

Despite the growing popularity and therapeutic potential of nutraceuticals, several challenges remain regarding their regulation, standardization, quality control, and scientific validation. Regulatory frameworks for nutraceuticals vary widely across countries, leading to inconsistencies in product classification, labeling, and safety evaluation (Zeisel, 1999). Furthermore, many nutraceutical products lack sufficient clinical evidence to support their therapeutic claims, highlighting the need for large-scale human studies and evidence-based research (Aronson, 2017).

Quality assurance is another important concern because variations in cultivation, extraction, processing, and storage conditions can influence the composition and efficacy of nutraceutical products (Borchers et al., 2016). In addition, interactions between nutraceuticals and pharmaceutical drugs may result in adverse effects or altered therapeutic outcomes, emphasizing the need for proper healthcare guidance and consumer awareness.

METHODOLOGY

The literature data was collected via Core Collection, Web of Science, Google Scholar, Scopus, Science Direct, PubMed, MDPI, Clarivate Analytical, Google Academic, and Scientific Electronic Library Online (SciELO) from 1990-21. The search terms were nutraceuticals, food supplements, medicinal food, and functional food. These articles were considered on the basis of their nutraceutical and therapeutical uses with scientific proof.

Table 1. Classification of Nutraceuticals Based on Source and Therapeutic Potential

Classification	Examples	Major Bioactive Components	Therapeutic Potential	References
Functional Foods	Oats, tomatoes, salmon, yogurt	Beta-glucan, lycopene, omega-3 fatty acids, probiotics	Cardioprotective, anticancer, gut health improvement, anti-inflammatory activity	Shahidi (2009); Santini et al. (2017)
Dietary Supplements	Vitamins, minerals, amino acids	Vitamin C, Vitamin D, zinc, iron	Immune enhancement, antioxidant effects, bone health, metabolic regulation	Kalra (2003); Nasri et al. (2014)

Herbal Nutraceuticals	Turmeric, garlic, ginger, ginseng	Curcumin, allicin, gingerol, ginsenosides	Antioxidant, antimicrobial, anti-inflammatory, anticancer activities	Pandey et al. (2010); Puri et al. (2022)
Probiotics	Lactobacillus, Bifidobacterium	Beneficial live microorganisms	Gastrointestinal health, immune modulation, improved digestion	Hardy (2000); Santini & Novellino (2018)
Prebiotics	Inulin, fructooligosaccharides	Non-digestible fibers	Gut microbiota regulation, enhanced mineral absorption	Hardy (2000); Stephen et al. (2017)
Fortified Foods	Fortified cereals, milk, beverages	Added vitamins and minerals	Prevention of nutritional deficiencies, bone health support	Shahidi (2009); Zeisel (1999)
Polyunsaturated Fatty Acids (PUFAs)	Fish oil, flaxseed oil	EPA, DHA, alpha-linolenic acid	Cardioprotective, neuroprotective, anti-inflammatory effects	Sirtori et al. (2009); Puri et al. (2022)
Phytochemicals	Fruits, vegetables, tea	Polyphenols, flavonoids, carotenoids	Antioxidant, anticancer, anti-aging activities	Shahidi (2009); Nasri et al. (2014)

Table 2. Classification of Nutraceuticals Based on Chemical Nature

Chemical Class	Examples	Natural Sources	Therapeutic Potential	References
Carotenoids	Beta-carotene, lycopene	Carrots, tomatoes	Antioxidant, anticancer, eye health protection	Das et al. (2012); Shahidi (2009)

Flavonoids	Quercetin, catechins	Tea, onions, apples	Anti-inflammatory, cardioprotective, antioxidant	Santini et al. (2017); Nasri et al. (2014)
Polyphenols	Resveratrol, curcumin	Grapes, turmeric	Neuroprotective, anti-aging, anticancer	Puri et al. (2022); Santini & Novellino (2018)
Dietary Fibers	Pectin, beta-glucan	Fruits, oats	Cholesterol reduction, digestive health	Stephen et al. (2017); Das et al. (2012)
Fatty Acids	Omega-3 fatty acids	Fish oils, flaxseed	Cardiovascular protection, anti-inflammatory activity	Sirtori et al. (2009)
Vitamins	Vitamins A, C, D, E	Fruits, vegetables, dairy products	Antioxidant, immune enhancement, bone health	Kalra (2003); Puri et al. (2022)
Minerals	Zinc, selenium, calcium	Nuts, dairy products, legumes	Immune support, enzyme activation, bone development	Nasri et al. (2014)
Probiotic Microorganisms	Lactobacillus species	Yogurt, fermented foods	Gut health, improved immunity	Hardy (2000); Santini et al. (2017)

Table 3. Therapeutic Applications of Major Nutraceuticals

Nutraceutical	Source	Mechanism of Action	Therapeutic Applications	References
Curcumin	Turmeric	Inhibits inflammatory mediators and oxidative stress	Arthritis, cancer, neurodegenerative disorders	Nasri et al. (2014); Puri et al. (2022)
Resveratrol	Grapes, berries	Antioxidant and anti-inflammatory action	Cardiovascular diseases, aging, diabetes	Santini et al. (2017)
Omega-3	Fish oil	Modulates	Cardiovascular	Sirtori et al.

Fatty Acids		inflammatory pathways	diseases, depression, arthritis	(2009)
Probiotics	Fermented foods	Maintains gut microbiota balance	Gastrointestinal disorders, immunity enhancement	Hardy (2000)
Lycopene	Tomatoes	Neutralizes free radicals	Prostate cancer prevention, cardiovascular protection	Das et al. (2012)
Catechins	Green tea	Antioxidant and anticancer activity	Obesity, cancer prevention, metabolic disorders	Shahidi (2009)
Beta-glucan	Oats, barley	Lowers serum cholesterol	Hyperlipidemia, cardiovascular diseases	Stephen et al. (2017)
Vitamin D	Fish, fortified milk	Calcium regulation and immune modulation	Osteoporosis, immune disorders	Kalra (2003)
Zinc	Nuts, legumes	Supports enzymatic and immune functions	Immune deficiency, wound healing	Nasri et al. (2014)

Table 4. Classification of Nutraceuticals Based on Mechanism of Action

Mechanism	**Nutraceutical Examples**	**Pharmacological Activity**	**Therapeutic Importance**	**References**
Antioxidant	Vitamin C, Vitamin E, polyphenols	Neutralization of reactive oxygen species	Prevention of oxidative stress-related diseases	Shahidi (2009); Nasri et al. (2014)
Anti-inflammatory	Curcumin, omega-3 fatty acids	Suppression of inflammatory cytokines	Arthritis, cardiovascular diseases	Sirtori et al. (2009)
Anticancer	Lycopene, catechins, resveratrol	Inhibition of tumor growth and angiogenesis	Cancer prevention and supportive therapy	Santini et al. (2017)

Immunomodulatory	Probiotics, zinc, Vitamin D	Enhancement of immune responses	Infection prevention and immune support	Hardy (2000); Kalra (2003)
Hypocholesterolemic	Beta-glucan, plant sterols	Reduction of LDL cholesterol	Cardiovascular disease prevention	Stephen et al. (2017)
Neuroprotective	Omega-3 fatty acids, resveratrol	Protection against neuronal damage	Alzheimer's disease, Parkinson's disease	Santini & Novellino (2018)

Phytochemicals as Nutraceutical Ingredients

Plants comprise primary and secondary metabolites, which showed and play various styles of functions. The primary metabolites, which play a vital position in mobile strategies, may be simple sugar, carbohydrates, nucleic acids, lipids, and amino acids. Secondary metabolites are as follows.

Carotenoids

The carotenoids are observed in exceptional colorings and nature, e.g., carrots orange, corn yellow, tomato red, salmon, flamingos, goldfish, and autumn leaves, while "chlorophyll" has gone via the leaves, simplest carotenoids and phenols continue to be. The bell peppers of various colorations offer a ramification of various carotenoids:

Orange carotenoids: alpha, beta, and gamma carotene.

Red carotenoids: lycopene and astaxanthin.

Yellow carotenoids: lutein and zeaxanthin.

Plants produce more than six hundred carotenoids, and the handiest 50 carotenoids in the human weight-reduction plan are absorbed into the bloodstream. The α, β, and some other carotenoids ("not lycopene or lutein") may be transformed to vitamin A. Hypervitaminosis of vitamin A cannot be because of immoderate α- and β-carotene intakes since the switch and absorption rates are too gradual. Each of the carotenes (α-carotene and β-carotene) is protecting against liver and lung cancers in the cell way of life and animal research. The most lipid-rich (LDL) cholesterol particles are transported by means of carotenoids into blood movement and get hold of the maximum LDL receptors.

Lycopene

Lycopene is found in watermelon, tomatoes, pink grapefruit, papaya, and guava and additionally offers red color. It is a potent antioxidant compound that reduces damage to DNA and proteins and additionally offers better pores and skin safety in opposition to extremely violet light than β-carotene. It is utilized in most cancer protection and decreases LDL levels of cholesterol and suppresses insulin-like increase elements, which stimulates tumor boom.

β-Carotene

β-Carotene is a much less lively antioxidant, however robust in opposition to singlet oxygen, their components can fairly enrich β-carotene content and LDL cholesterol without affecting different carotenes, they are able to increase the pastime of herbal killer "T-cells, β-cells, and NK cells," and energizing "DNA" mend enzymes and grant higher cornea safety in opposition to extremely violet light than lycopene.

α-Carotene

α-Carotene is 10 instances stronger and a more effective anticarcinogenic compound in assessment than β-carotene, because of the let out of immunogenic cytokines (IL-1 and TNF-α).

Lutein

Lutein produces yellow color in nature through the exceptional types of resources, e.g., corn, avocado, and egg yolk. It protects and therapies the attention, from macular degeneration and cataracts, which shield against colon cancer. Its maximum concentration or quantity is located in kale, spinach, watercress, and parsley.

Astaxanthin

Astaxanthin gives different colors to salmon, shrimp, and crab. It is a potent antioxidant rather than any other carotenoid. It is also improved T-cell manufacturing and cytokine, which releases and crosses the "blood-brain barrier" (BBB) brain antioxidant and authorizes it to liberate trapped absolutely to vitamin C.

Saponins

Saponins are a legume's own family medicinal plant, the ones that occur in chickpeas and soybeans and eliminate LDL cholesterol. They are effective in opposition to colon cancers and a few other crucial troubles.

Terpineol

Terpineol produces carrot flavor from carrots, and the origin cellular pattern is detained in most cancer stalls. They are water-insoluble chemical compounds, classified as hydrocarbon constituents by isoprene units and a high class of secondary metabolites. It is used in exhibiting antimicrobial and cytotoxic potential.

Anthocyanins

Anthocyanins are water-soluble, anti-inflammatory glycosides and acryl-glycosides; they make roses red, cherries, strawberries, blueberries, and violet-blue. Blueberries increase anthocyanin contents when ripened and are easily damaged by heat (cooking).

Flavonoids

Flavonoids (flavone-like) are antioxidant and anti-inflammatory nature chemical compounds, which are present in dark chocolate and red wine and absent in white wine, due to their different extraction methods, where red wine is prepared or made by the fermentation method, although ultrafiltration is every now and then used to reduce astringency and bitterness. It is used for those patients, who are suffering from radiation and chemotherapy.

Rutin

It is determined in asparagus, buckwheat, and citrus quit end result, which is not misplaced in drying grapes to raisins and strengthens arteriole partitions.

Quercetin

Quercetin ("flavanol") which is the mighty antioxidant is present in green tea, red onions, buckwheat, and red grapes, which is distinctly available in the skins of apples and decreases LDL oxidation and is a vasodilator and blood thinner and might kill viruses. It is used to relieve allergy, inhibit catechol-O-methyl transferase (COMT) enzymes, reduce epinephrine, inhibit heart stroke protein and antihistaminic activity, and also promote apoptosis in cancer and other cells.

Tannins

Tannins (polyphenolics) are used to tan and defend leather-based seen in the 18th century A.D., which makes cranberries and pomegranates sour. It together with vitamin C helps to construct and improve collagen. It prevents UTI ("urinary tract infection") with the useful resource of stopping microorganisms (bacteria) from adhering to the partitions. While blended with anthocyanins ("as in pomegranate juice"), it damage down oxidized LDL cholesterol within the bloodstream and in the atherosclerotic plate. It available in maximum energetic shape is black tea, which includes 90% catechin and epicatechin in natural grapes.

Phenolic Acids

The phenolic compounds (proanthocyanidins, resveratrol, and ellagic acid) are found in red wine, grape juice, and raisins, which are fantastically found in cranberry juice, reducing oxidation of LDL cholesterol and adherence of bacteria to enamel/teeth and cellular lining of the bladder, thereby lowering UTI ("urinary tract infections") and tooth fairy. The sugar-coat nature compounds lessen the nonstick homes of phenolic. The phenolic acid formation of most cancers sells nitrosamines from dietary nitrate and nitrites.

Ellagic Acid

Ellagic acid is determined in strawberries and raspberries but is 50% greater in raspberries; it reduces esophageal and colorectal cancers, which retard the process of DNA adducts, retard stage 1, and potentiate phase-2 adjuvant (Das et al., 2012).

Amino Acids

The amino acids are playing a significant role in anti-inflammatory, immunomodulatory, and antioxidant properties. These are used in protein biosynthesis and many others, e.g., L-arginine is used for infant or children growth, pregnant women, and synthesis of agmatine, urea, creatine, polyamines, and nitric oxide. It is also useful for antihypertensive and antiproliferative effects on vascular smooth muscles. Glutamine is essential for metabolic stress, burn injury, muscle wasting, weight loss, and other infections with depletion of plasma. It has been shown to gain patients and decreases the mortality rate by elevating the level of amino acids in staple meals which include rice, wheat, corn, and different flora.

Future Prospectives

The increasing demand for nutraceuticals, such as food for fitness and health, is responsible for their positive and therapeutic uses for different kinds of diseases. The development and growth of new functional food or specially nutraceutical industry seem destined to occupy the landscape in the new millennium. The enzymes are used in various nutraceutical processes and play a crucial part in nutraceuticals. The next area of high consideration is the interaction between nutraceuticals and FDA. The therapeutic effectiveness of nutraceuticals remains to be determined as like drugs.

It is a big challenge for nutraceuticals, for the future prevention and therapy of triggering tools in the medicine area. The future possibility of nutraceuticals to prevent or support a pharmacological therapy is now recently based on pharmaceuticals, which can be a powerful tool to face pathological, chronic, and long-term diseases. The clinical study data evaluation is based on the beneficial effect of nutraceuticals, through "in vitro and in vivo" representation, which may be dispensed in an individual nutritive supplementation observed in animals.

CONCLUSIONS

Despite the increasing popularity of nutraceuticals, challenges related to standardization, safety evaluation, regulatory frameworks, quality control, and scientific validation remain significant barriers to widespread clinical acceptance. Therefore, evidence-based research and stringent regulatory oversight are essential to ensure the efficacy and safety of nutraceutical products. By bridging the gap between nutrition and pharmacology, nutraceuticals represent a promising complementary approach in modern healthcare, with the potential to support preventive medicine and enhance overall quality of life.

Conflicts of Interest

The author declares no conflicts of interest.

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